Assignment 3 : SDN and Ryu

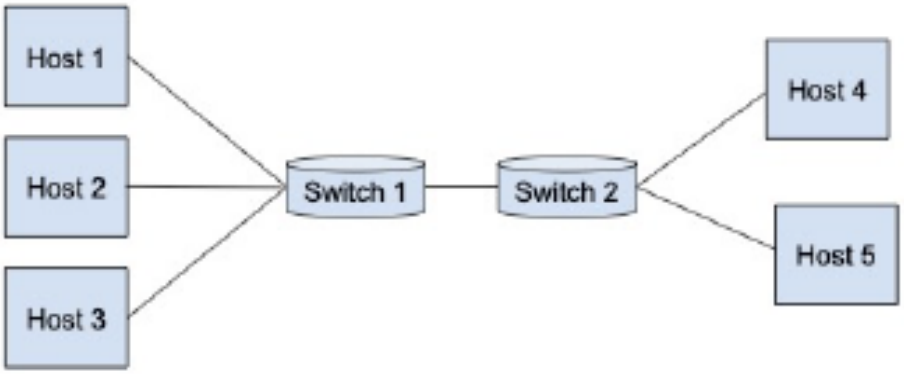


Figure 1: Custom Topology

Part 1: Controller Hub and Learning Switch

Answer1:

Controller Hub

A Hub Controller operates by broadcasting incoming network traffic to all switch ports except the incoming one, essentially flooding traffic to all devices connected to the switch. It does not have the intelligence to make forwarding decisions based on the destination MAC address.

mininet> h2 ping -c 3 h5
PING 10.0.0.5 (10.0.0.5) 56(84) bytes of data.
64 bytes from 10.0.0.5: icmp_seq=1 ttl=64 time=**22.8** ms
64 bytes from 10.0.0.5: icmp_seq=2 ttl=64 time=**5.99** ms
64 bytes from 10.0.0.5: icmp_seq=3 ttl=64 time=**3.35** ms

--- 10.0.0.5 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2005ms
rtt min/avg/max/mdev = 3.345/10.719/22.824/8.626 ms

ryu-manager:

packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3

Learning Switch

In contrast, a Learning Switch is more efficient and intelligent. It learns MAC to Port mappings from incoming traffic and installs flow rules on the switches accordingly. This enables it to make forwarding decisions based on the destination MAC address, reducing unnecessary network broadcast traffic and improving network efficiency.

mininet> h2 ping -c 3 h5
PING 10.0.0.5 (10.0.0.5) 56(84) bytes of data.
64 bytes from 10.0.0.5: icmp_seq=1 ttl=64 time=**24.5** ms
64 bytes from 10.0.0.5: icmp_seq=2 ttl=64 time=**0.218** ms
64 bytes from 10.0.0.5: icmp_seq=3 ttl=64 time=**0.052** ms

--- 10.0.0.5 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2020ms
rtt min/avg/max/mdev = 0.052/8.251/24.485/11.478 ms
mininet>

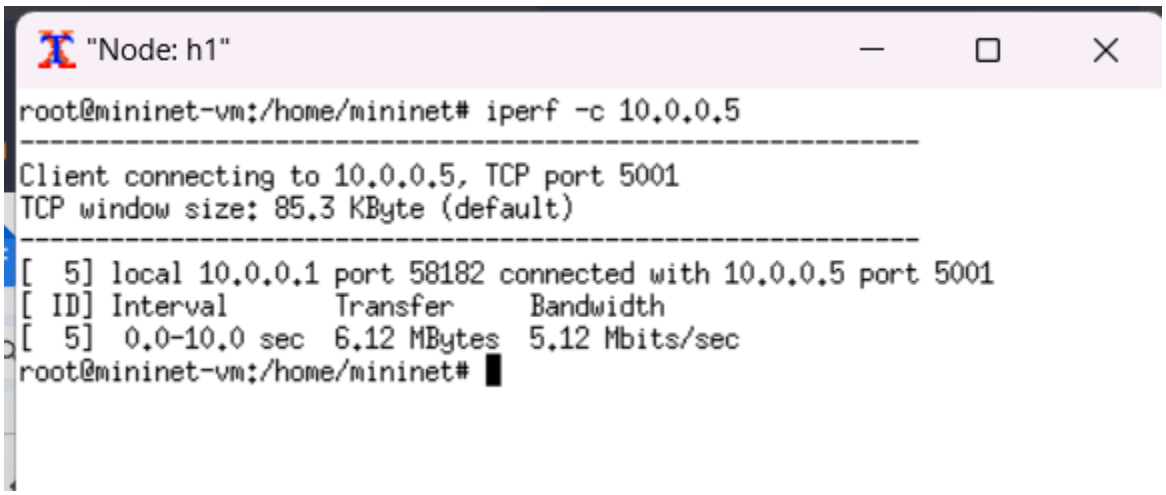
ryu-manager

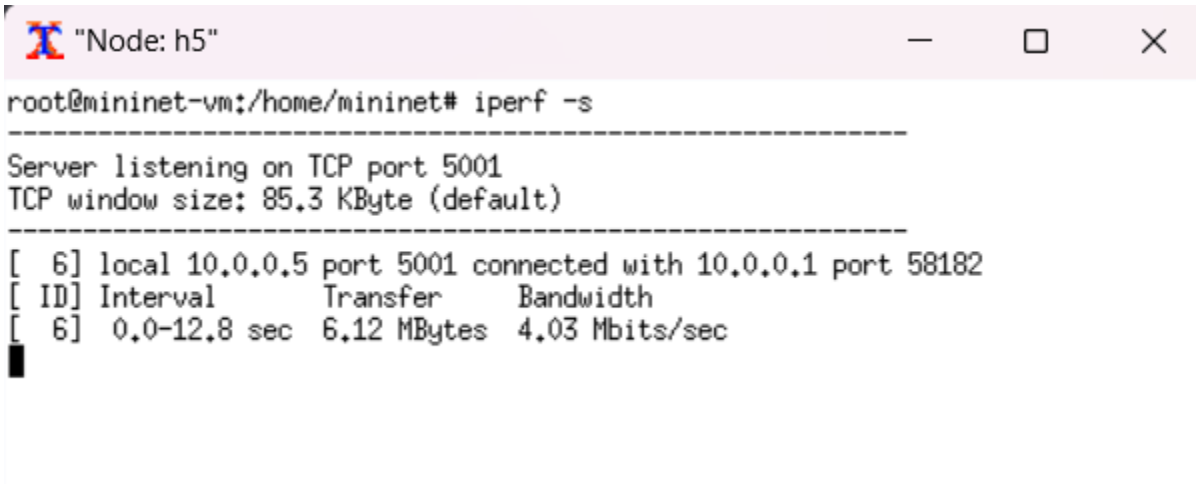
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3

Difference between controller Hub and Learning switch:
Here when we run the ping 3 times between 2 same hosts h2 and h5 the time to ping doesn’t decreases drastically in controller hub because it floods the request for every ping to know the destination and also doesnot stores the state.

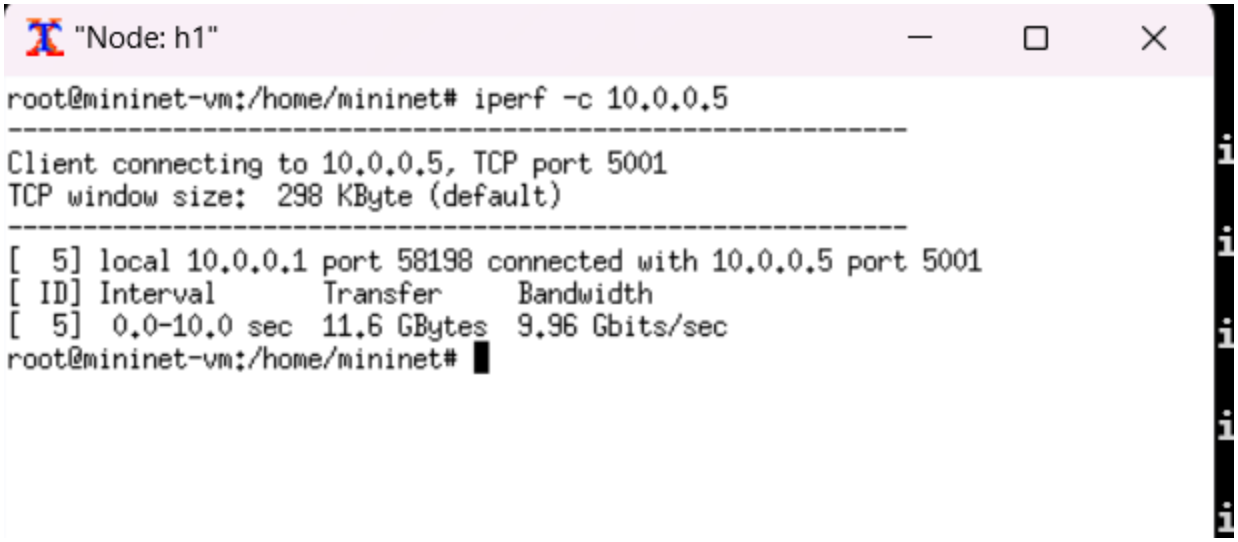
In the learning switch the request is only flooded initially whereas for the next two pings it follows the stored state to reach the destination.Since flooding is reduced so time decreases.

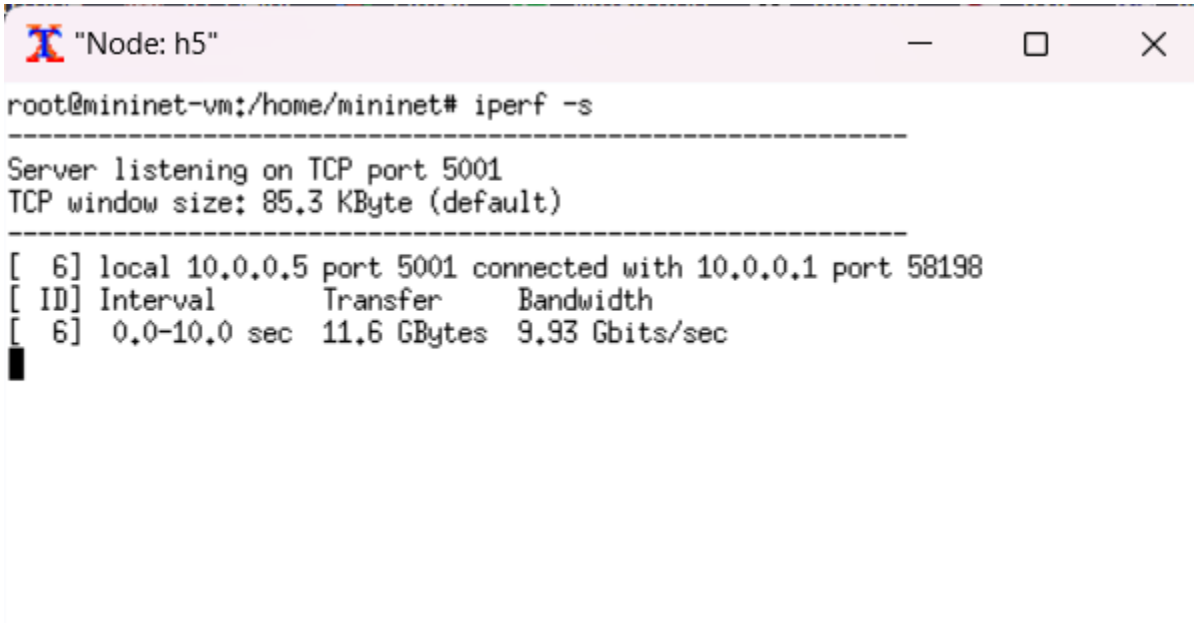
Run a throughput test between h1 and h5. Report the observed values. Explain the differences
between the Hub Controller and Learning Switch.
Controller Hub:





Learning Switch





The throughput is better in case of learning switch because of the reduction in network traffic by eliminating redundant flood packets.

Run pingall in both cases and report the installed rules on switches.

Controller Hub:

mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4 h5
h2 -> h1 h3 h4 h5
h3 -> h1 h2 h4 h5
h4 -> h1 h2 h3 h5
h5 -> h1 h2 h3 h4
*** Results: 0% dropped (20/20 received)

ryu-manager:

packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 3

packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3

Learning Switch

mininet> pingall

*** Ping: testing ping reachability

h1 -> h2 h3 h4 h5

h2 -> h1 h3 h4 h5

h3 -> h1 h2 h4 h5

h4 -> h1 h2 h3 h5
h5 -> h1 h2 h3 h4
*** Results: 0% dropped (20/20 received)
Ryu-manager:

packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 1

Part 2: Firewall and Monitor

> Run pingall and report the results.
root@mininet-vm:/home/mininet# python3 topology.py
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 X h5
h2 -> h1 h3 h4 X
h3 -> h1 h2 h4 X
h4 -> X h2 h3 h5
h5 -> h1 X X h4
*** Results: 30% dropped (14/20 received)

Ryu-manager:

```
root@mininet-vm:/home/mininet# ryu-manager firewall_monitor.py
loading app firewall_monitor.py
loading app ryu.controller.ofp_handler
instantiating app firewall_monitor.py of LearningSwitch
instantiating app ryu.controller.ofp_handler of OFPHandler
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:01 , portNo: 3
Packet count for h3 on switch s1: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:01 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
```

packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:02 , portNo: 3
Packet count for h3 on switch s1: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 2
packet in switch : 2 , source host: 00:00:00:00:00:02 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:02 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
Packet count for h3 on switch s1: 3
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
Packet count for h3 on switch s1: 4
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:04 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
Packet count for h3 on switch s1: 5
packet in switch : 2 , source host: 00:00:00:00:00:03 , destination host: ff:ff:ff:ff:ff:ff , portNo: 3
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:03 , portNo: 4
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:01 , destination host: 00:00:00:00:00:04 , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 1
packet in switch : 2 , source host: 00:00:00:00:00:05 , destination host: 00:00:00:00:00:04 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:04 , destination host: ff:ff:ff:ff:ff:ff , portNo: 4
packet in switch : 2 , source host: 00:00:00:00:00:04 , destination host: 00:00:00:00:00:05 , portNo: 1
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:02 , destination host: 00:00:00:00:00:05 , portNo: 2
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3
packet in switch : 1 , source host: 00:00:00:00:00:03 , destination host: 00:00:00:00:00:05 , portNo: 3

Here the hosts to which the packet should not be sent are implemented and reflected in output.
This ryu-manager output counts the packets by h3 on s1.

Rules implemented on both switches:
mininet> dpctl dump-flows

```
*** s1 ------------------------------------------------------------------------
        cookie=0x0, duration=192.003s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:01 actions=output:"s1-eth1"
        cookie=0x0, duration=192.003s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:02 actions=output:"s1-eth2"
        cookie=0x0, duration=191.982s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:01 actions=output:"s1-eth1"
        cookie=0x0, duration=191.973s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:03 actions=output:"s1-eth3"
        cookie=0x0, duration=191.951s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01 actions=output:"s1-eth1"
        cookie=0x0, duration=181.909s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01 actions=output:"s1-eth1"
        cookie=0x0, duration=181.898s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05 actions=output:"s1-eth4"
        cookie=0x0, duration=181.834s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:02 actions=output:"s1-eth2"
        cookie=0x0, duration=181.822s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:03 actions=output:"s1-eth3"
        cookie=0x0, duration=181.784s, table=0, n_packets=3, n_bytes=238,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02 actions=output:"s1-eth2"
        cookie=0x0, duration=181.780s, table=0, n_packets=2, n_bytes=140,
priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04 actions=output:"s1-eth4"
        cookie=0x0, duration=181.736s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02 actions=output:"s1-eth2"
        cookie=0x0, duration=171.716s, table=0, n_packets=4, n_bytes=280,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03 actions=output:"s1-eth3"
        cookie=0x0, duration=171.712s, table=0, n_packets=3, n_bytes=182,
priority=1,in_port="s1-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04 actions=output:"s1-eth4"
        cookie=0x0, duration=171.689s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s1-eth4",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03 actions=output:"s1-eth3"
     cookie=0x0, duration=194.588s, table=0, n_packets=43, n_bytes=2478, priority=0
actions=CONTROLLER:65535


*** s2 ------------------------------------------------------------------------
        cookie=0x0, duration=192.030s, table=0, n_packets=4, n_bytes=224,
priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:01 actions=output:"s2-eth3"
```

cookie=0x0, duration=181.994s, table=0, n_packets=3, n_bytes=238, priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:01 actions=output:"s2-eth3"
cookie=0x0, duration=181.958s, table=0, n_packets=2, n_bytes=140, priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:05 actions=output:"s2-eth2"
cookie=0x0, duration=181.873s, table=0, n_packets=3, n_bytes=238, priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:02 actions=output:"s2-eth3"
cookie=0x0, duration=181.850s, table=0, n_packets=2, n_bytes=140, priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:02,dl_dst=00:00:00:00:00:04 actions=output:"s2-eth1"
cookie=0x0, duration=181.824s, table=0, n_packets=4, n_bytes=224, priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:02 actions=output:"s2-eth3"
cookie=0x0, duration=171.796s, table=0, n_packets=4, n_bytes=280, priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:03 actions=output:"s2-eth3"
cookie=0x0, duration=171.784s, table=0, n_packets=3, n_bytes=182, priority=1,in_port="s2-eth3",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:04 actions=output:"s2-eth1"
cookie=0x0, duration=171.767s, table=0, n_packets=4, n_bytes=224, priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:03 actions=output:"s2-eth3"
cookie=0x0, duration=151.673s, table=0, n_packets=3, n_bytes=238, priority=1,in_port="s2-eth2",dl_src=00:00:00:00:00:05,dl_dst=00:00:00:00:00:04 actions=output:"s2-eth1"
cookie=0x0, duration=151.666s, table=0, n_packets=2, n_bytes=140, priority=1,in_port="s2-eth1",dl_src=00:00:00:00:00:04,dl_dst=00:00:00:00:00:05 actions=output:"s2-eth2"
cookie=0x0, duration=194.662s, table=0, n_packets=21, n_bytes=1106, priority=0 actions=CONTROLLER:65535

Minimizing the number of firewall rules on switches:

1) Group similar rules together and avoid redundancy. For example, if you have multiple rules for different VLANs with similar access requirements, create a single rule that covers all of them.
2) Instead of creating rules for individual IP addresses, group hosts into IP subnets or CIDR blocks.
3) Rather than creating rules for each individual port and protocol, consider grouping rules by service or application. For example, instead of creating separate rules for HTTP and HTTPS, create a rule for "Web Traffic" that covers both.
4) Some security functions can be offloaded to dedicated IDS/IPS devices, which can reduce the need for complex switch rules.

> Suppose the network operator intends to implement firewall policies in real time. How can she ensure that the pre-existing rules do not interfere with the firewall policy?
Answer: Implement logging and monitoring for your firewall rules. This helps in quickly identifying issues and conflicts. You can use tools like iptables-restore or nftables to update rules and monitor rule changes in real-time. Also specify the rule and run it and test it in real time and see whether it clashes with any existing rules if yes than it should be statically checked if not clashed it can be implemented dynamically.

Part 3: Load Balancer

>Have the three hosts (H1, H2, and H3) ping the virtual IP and report the installed rule on the switches.

```
mininet> h1 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.

--- 10.0.0.42 ping statistics ---
1 packets transmitted, 100% received, 0% packet loss, time 0.5ms

mininet> h2 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.

--- 10.0.0.42 ping statistics ---
1 packets transmitted, 100% received, 0% packet loss, time 0.6ms

mininet> h3 ping -c 1 10.0.0.42
PING 10.0.0.42 (10.0.0.42) 56(84) bytes of data.

--- 10.0.0.42 ping statistics ---
1 packets transmitted, 100% received, 0% packet loss, time 0.5ms

mininet> dpctl dump-flows
```

*** s1 ----------
cookie=0x0, duration=68.986s, table=0, n_packets=6, n_bytes=420, priority=0 actions=CONTROLLER:65535
*** s2 ----------
cookie=0x0, duration=68.993s, table=0, n_packets=0, n_bytes=0, priority=0 actions=CONTROLLER:65535

root@mininet-vm:/home/mininet ryu-manager load_balancer.py
loading app load_balancer.py
loading app ryu.controller.ofp_handler
instantiating app load_balancer.py of Switch
instantiating app ryu.controller.ofp_handler of OFPHandler
Server selected: 10.0.0.4
Packet from client: 10.0.0.1. Sent to server: 10.0.0.4, MAC: 00:00:00:00:00:04 and on switch port: 1
Reply sent from server: 10.0.0.4, MAC: 00:00:00:00:00:04. Via load balancer: 10.0.0.42. To client: 10.0.0.1
Server selected: 10.0.0.5
Packet from client: 10.0.0.2. Sent to server: 10.0.0.5, MAC: 00:00:00:00:00:05 and on switch port: 2
Reply sent from server: 10.0.0.5, MAC: 00:00:00:00:00:05. Via load balancer: 10.0.0.42. To client: 10.0.0.2
Server selected: 10.0.0.4
Packet from client: 10.0.0.3. Sent to server: 10.0.0.4, MAC: 00:00:00:00:00:04 and on switch port: 1
Reply sent from server: 10.0.0.4, MAC: 00:00:00:00:00:04. Via load balancer: 10.0.0.42. To client: 10.0.0.3

Here we are able to balance load using the logic that every time a arp request is made the server which was assigned previously to the previous ARP request isn't the one which is assigned to this ARP request.
This is clear using the output of the ryu-manager and flow tables of switches which doesn't store any state to allow this.
> If you were to implement a load balancing policy that considers the load on these servers, what additional steps would you take? [No need to implement it in the code, just describe the additional steps.

Answer: To implement a load balancing policy that considers the load on servers, Set up a monitoring system to continuously collect data on the load, performance, and resource utilization of each server in your server list. Define a load metric that quantifies the current load on each server. The load metric can be a weighted combination of various performance metrics, depending on the specific load balancing strategy we want to implement. For example, we might assign higher weights to servers with lower CPU utilization or lower request latency. Modify the load balancing policy to consider the load metric when selecting a server. Instead of simply cycling through servers as in our current code, select the server that has the lowest load based on the load metric. We may need to implement a decision-making algorithm to make this selection, such as round-robin with load awareness, weighted least connections, or least load.